National Aeronautics and Space Administration

Safe Constellation Flying Requires Awareness

Paul Frakes
NASA Robotic Conjunction Assessment

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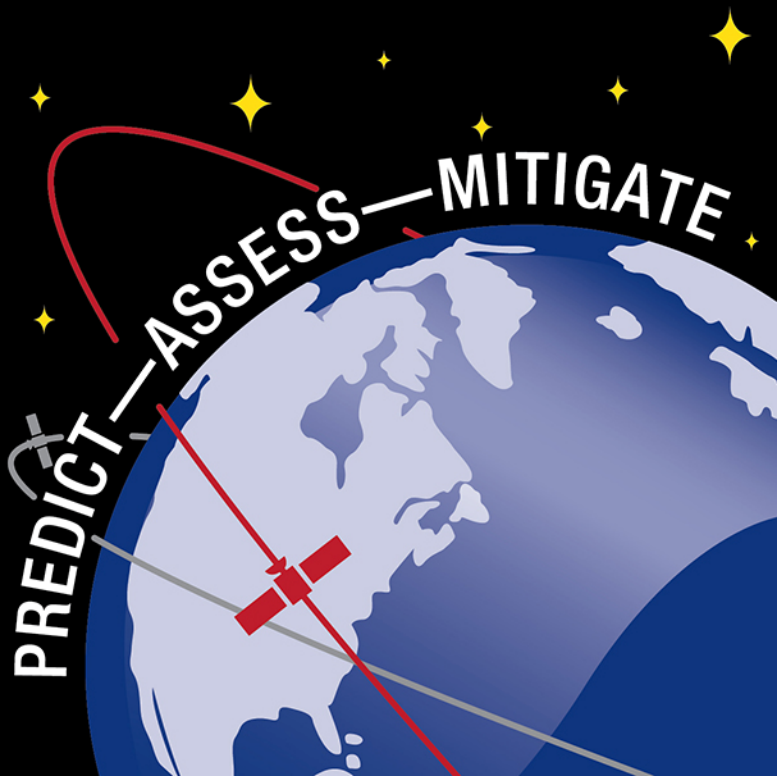

NASA ROBOTIC CARA

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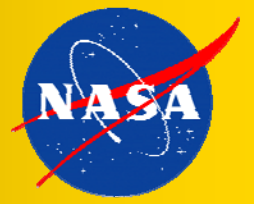
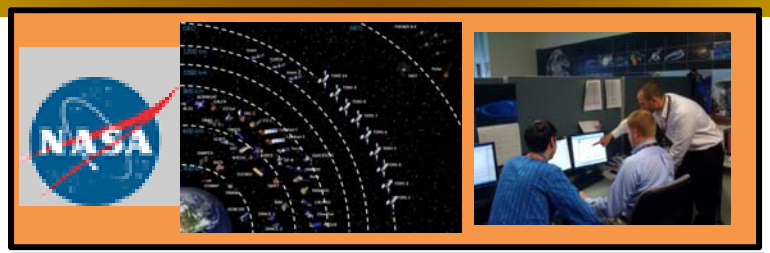
Flight Safety Requires Awareness



- Flight requirements awareness
  - e.g. NASA Procedural Requirement (NPR) 8715.6a
- Technical understanding
  - NASA Robotic Conjunction Assessment Risk Analysis (CARA) Team
- Communication/coordination
  - Space is congested by many unique owner/operators (O/O)

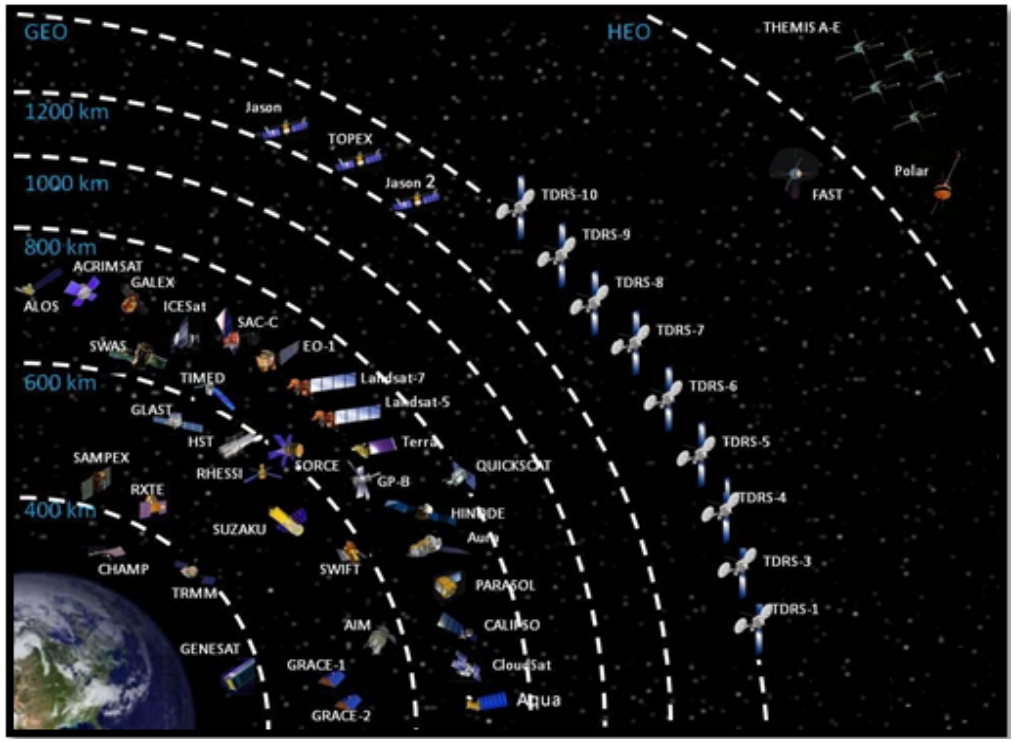
Conjunction Assessment Risk Analysis (CARA) Operational Process Overview



	JSpOC (VAFB)	NASA Robotic CARA Team (NASA GSFC)	Mission Operations Teams (Global)
Area of Responsibility	• Maintain High Accuracy Space Object Catalog • Interface with Space Surveillance Network • Request Increase Tracking Data Collects	• Perform CA Risk Analysis • Interface with JSpOC analysts to ensure data product delivery & quality • Assist Mission Operations Teams with avoidance maneuver strategy	• Provide ephemeris (state & covariance) to NASA Robotic CARA Team for evaluation • Weigh CA event risk against other mission risks
Products	• Generate daily close approach predictions • Provide state and state uncertainty information for primary and secondary objects • Provide miss distance Summaries • Provide object tracking information	• Automated event reporting • Conjunction event trending • Qualitative assessment of orbit determination solutions • Conjunction geometry examination • Recommendations to Mission Operations Team	• Avoidance maneuver planning • Maneuver execution

Missions Supported

- Robotic CARA team supports ~60 spacecraft in LEO, GEO, and HEO orbits, including:
  - All Operational NASA unmanned satellites
  - USGS
  - NOAA
  - Foreign partner missions
  - Commercial companies
- JSC supports Manned Spaceflight (ISS and visiting vehicles).



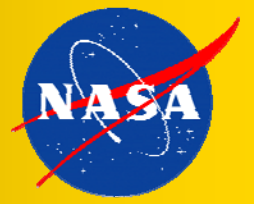
The Conjunction Assessment Risk Analysis mission at NASA GSFC is to protect NASA robotic assets from threats posed by other space objects while operating in the space environment through ensuring domain expertise, a robust concept of operations, and an operationally-responsive system to meet the expanding needs of the mission area

Flight Safety Challenges

1. Proliferation of CubeSats increases collision risk
   - ISS deployments
   - Secondary payloads
   - Non-traditional operators, e.g. student groups
2. Satellite co-locations pose systematic collision risk
   - Certain orbits particularly valuable for specific applications
   - Possible to launch a satellite into orbital location where other satellite(s) are already operating
3. Communication process between owner/operators of operational spacecraft is not always robust
   - Particularly true for international parties

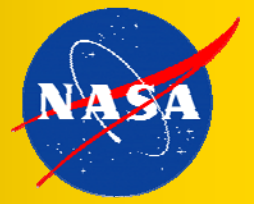
- In the following charts, these challenges are discussed and potential solutions are proposed
  - Orbital registry
  - Standard communication template

CubeSats: Case Study



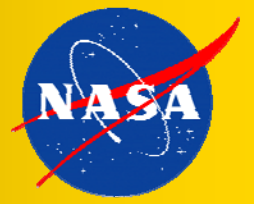
- Throughout the month of February 2014, a constellation of CubeSats known as Flock-1 was deployed from the ISS
- The Global Precipitation Measurement (GPM) mission launched into a near-circular orbit very close to ISS altitude on February 27
  - GPM did not have the ability to perform maneuvers immediately after launch
- Both spacecraft had NASA involvement, so communication channels were opened prior to GPM launch to determine risk posed and mitigation options
  - GPM: joint NASA/JAXA, Flock-1: PlanetLabs payloads deployed by NASA
- Coordination between ISS and GPM operations teams allowed risk to be communicated and avoided to the extent possible
  - No high risk events were encountered during GPM's early orbit phase
- Regular discussions now take place between operators at the ISS altitude to ensure activities are coordinated to reduce collision risk

Co-Locations Cause Collision Risk



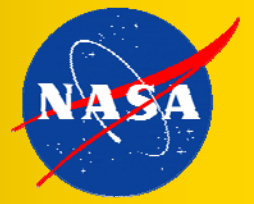
- The International Telecommunications Union (ITU) currently assures that no two spacecraft are placed such that Radio Frequency Interference exists between them
- No similar mechanism exists to ensure that new orbit assignments are chosen to avoid co-location with existing spacecraft
- Historically, repeating conjunctions that could have been avoided have resulted from poor placement choices
  - Landsat-5 changed its mission orbit many years after launch and passed through the A-Train constellation
  - SDO co-located with SkyTerra 1 and MSAT-M2; GOES co-located with BrazilSat because no checks were done pre-launch to look for neighbors
  - EO-1 was co-manifested with SAC-C without a separation plan, resulting in systematic close approaches post-launch
  - ISS moved to TRMM altitude after Shuttle ended
- Missions in formulation, missions making a change to their existing orbit, and missions moving to a disposal/decommissioning orbit are potential sources of systematic (repeating) conjunctions

Landsat Tiger Team



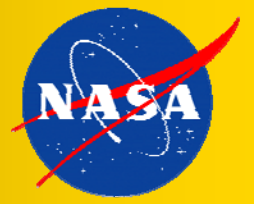
- In February 2010, Landsat-5 was periodically experiencing unreported close approaches with A-Train constellation missions
- It was determined that a change in mission orbit had caused Landsat-5 to walk through the constellation, causing close approaches with each member mission
- A Tiger Team was formed to determine why the close approaches had gone unreported
  - An algorithm to eliminate object self screening at the JSpOC prevented subscribers of the CARA (Conjunction Assessment Risk Analysis) system from being checked against other subscribers.
  - An updated operational procedure was implemented promptly after the discovery.
- The Tiger Team was also chartered with suggesting process improvements to prevent future close approaches
  - One suggestion was the formation of an Orbital Registry

Proposed Solution: NASA Orbital Registry



- An “Orbital Registry” capability is proposed to prevent such problems between spacecraft
- Orbital Registry would:
  - Be a central repository for orbit requirements definition
  - Proposed orbital placements or changes to existing orbits would be reported to the registry
  - Registry analysts determine whether a problem will ensue from the placement.
  - Recommendations are made for alternative placement
- Allows for advance notice of potential co-locations so that they can be avoided or managed smartly
- Reduces operations manpower required to mitigate systematic close approaches
- NASA only has enforcement power for issues between two NASA assets. Other assets would be managed voluntarily by the owner/operator

Expanded Orbital Registry

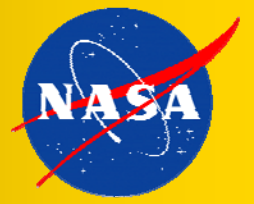


- The more organizations that participate, the more effective this mechanism will be.
- Other agencies could volunteer to share their information in a joint working group-type setting
  - Voluntary sharing of orbit requirements
  - Joint analysis of proposed placement could be performed to determine potential impacts and mitigation strategies
  - Changes to the proposed placement would be at the discretion of the launching agency
- In the short term, NASA would like to collect point of contact information for other operators to help to most efficiently resolve any close approach situations

Desired End State

- International registry collects data from all space operators to ensure co-locations are
  - Minimized
  - Predicted before launch
  - Mitigated appropriately
- Risk reduction:
  - All historical co-location cases mentioned in this package could have been prevented by an orbital registry capability
- Way ahead
  - Analyst staff to communicate with operators to collect and analyze data, and make recommendations will be needed proportional to the number of analysis requests
  - Combining the registry with the existing CARA staff and infrastructure provides a natural synergy with a team that has similar interfaces and skills.
  - Cost/resource sharing would be needed for the workload to be supported

Communication Challenges



- As space becomes more congested, effective and timely communication between O/O becomes increasingly important
  - JSpOC and Space Data Association (SDA) can provide information about conjunctions
  - O/O contact info not always available
    - Orbital registry provides means to collect this information
- NASA has developed a standard template for communicating conjunction risk and includes relevant information such as
  - Timing of conjunction
  - Risk level
  - Maneuver plans for the CARA-supported asset, if applicable
- NASA has used this template on several occasions to communicate a complete picture of the conjunction situation, including risk and mitigation plans
  - Including to international O/O

FSO Template Status: Template Sample (1 of 2)

Theoretical Example—fictitious data

To the operator of Envisat:

NASA has identified a close approach between the satellite Aura (satellite catalog number 28376) and the satellite Envisat (satellite catalog number 27386). The Time of Closest Approach (TCA) is 2014 Jan 23 12:34:56 UTC. The miss distance prediction as of 2014 Jan 17 18:00:00 UTC is 45.0 meters and the NASA Robotic Conjunction Assessment Risk Analysis (CARA) team is computing a Collision Probability of 1.42E-2, assuming a combined hard-body radius of 20 m.

We believe this close approach poses a high collision risk if neither satellite maneuvers. The owner-operator of Aura plans to maneuver its satellite between now and the time of closest approach. This maneuver is expected to mitigate the risk of collision. Is it possible to avoid maneuvering your satellite before the time of closest approach? If not and you are planning to execute a maneuver between now and time of closest approach, would it be possible to share your plans with the CARA Team in an effort to avoid a collision? If so, please share your plans in the form of (a) an ephemeris modeling the maneuver, or (b) pre- and post-maneuver state vectors.

Aura is currently planning a 5.2 cm/s orbit raise maneuver on 2014 Jan 20, at 18:00:00 UTC. We expect to provide status updates daily at approximately 15:00 UTC.

As of 2014 Jan 17 19:00:00 UTC, the current MJ2000 Predicted Post-Maneuver State Vector of Aura is

Epoch: 2014 Jan 20 18:15:00.000 UTC
<X, Y, Z; VX, VY, VZ> (km; km/s): <1234.000, 2345.000, 3456.000; 4.000000, 5.000000, 6.000000>

FSO Template Status: Template Sample (2 of 2)

Theoretical Example—fictitious data

NASA prefers that both spacecraft not maneuver to mitigate the risk of the same close approach, in order to prevent adding uncertainty to the problem. From a safety perspective, NASA prefers that any maneuver by one of the involved spacecraft not occur within 24 hours of a maneuver by the other involved spacecraft.

If your organization has established an account on Space-Track.org, the JSpOC may be able to provide you with Conjunction Summary Messages (CSMs) to assist in your risk assessment.

NOTE: You may receive an automated message from the US Joint Space Operations Center (JSpOC) containing information similar to what is presented here. The information contained in such an automated message may differ from the data presented here, although the data presented here do originate from the JSpOC as well.

If you have any questions, please contact the NASA Robotic Conjunction Assessment Risk Analysis (CARA) team via email at cara-ops@lists.nasa.gov; via the CARA Operations Center phone at +1-301-286-9545 from 0800-1600 US Eastern Time, Monday through Friday; or via the CARA on-call cell phone at +1-301-789-4306 outside of those hours.

Conclusion

- Effective planning and communication are essential to safety of flight for operational satellites
- The proposed orbital registry serves as a way to proactively mitigate on-orbit collision risk
- The standard communication template allows O/O to describe relevant conjunction information in a concise and timely manner